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A Virtual Commissioning Learning Platform

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Abstract

The introduction of reconfigurable manufacturing systems (RMS), Industry 4.0 and the associated technologies requires the establishment of new competencies. Towards that goal, Aalborg University (AAU) has developed an Industry 4.0 learning factory, the AAU Smart Production Lab. The AAU Smart Production Lab integrates a number of Industry 4.0 technologies for learning and research purposes. One of the many techniques is virtual commissioning. Virtual commissioning uses a virtual plant model and real controllers (PLCs) enabling a full emulation of the manufacturing system for verification. Virtual commissioning can lower the commissioning time up to 63%, allowing faster time to market. However, virtual commission is still missing industrial impact one of the reasons being lack of competencies and integration experiences. The paper presents the setup of the virtual commissioning learning platform and demonstrates how various students have worked with the platform acquiring knowledge in virtual commissioning. The construction of a virtual commissioning learning platform enabled a well-defined setup to support training of researchers, students, and companies.

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Keywords: Virtual Commissioning; Smart Production Lab; Learning Factory; Training Platform, Industry 4.0

1. Introduction

The introduction of mass customization and reconfigurable manufacturing systems (RMS) established the requirement for the development of certain skills in the production floor. In order to handle the oscillating market demand the question arises; how the required skills can be achieved? Moreover, the introduction of Industry 4.0 provides the necessity for new skills both in the industrial and the academic world.

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In the recent decade, Learning Factories have rapidly emerged as a platform for learning about new manufacturing strategies, novel technologies and exploration of new skills to learn [1-4]. In many cases, learning factories produce a dummy product, and are used both for teaching and research purposes [4]. The scope of the learning factories has substantial variants. A number of learning factories have a narrow scope e.g. are only used for PLC training whereas others have a more holistic scope focus on all aspects of a production such as production planning and optimisation, PLC and robot programming, production execution, and process optimisation. Many of the recent commissioned learning factories are based on some of the technical cornerstones of Industry 4.0 e.g., Cyber-physical systems, RFID-tags, robot technologies, and vertical and horizontal integration [2,3]. In addition, many of the learning factories utilise modules to embrace changeability and reconfigurability adopted from changeable and reconfigurable manufacturing systems [4]. One of the major challenges for a RMS is to reduce the commissioning time due to cost and extended time to market [5]. Traditionally, 15-25% of the project time in a manufacturing system, is used in the commissioning phase. In the commissioning phase itself, up to 63% of the time is used in debugging the software [6]. During its lifetime a RMS will undergo multiple commissions, thus, it is crucial to lower the commissioning time. Virtual commissioning (VC), is also known as hardware-in-the-loop verification, a tool to lower the commissioning time up to 75% with the use of virtual plants and real controllers [6]. Despite the fact that VC has been introduced almost two decades ago, it is still not widely used in industry partly due to the lack of the necessary competencies and experience [7,8]. Therefore, it is vital to provide an appropriate training platform where cross-disciplinary skills can be acquired. Towards that end, the main focus of this work is the presentation of a virtual commissioning learning platform (VCLP) built in order to obtain a well-defined setup where all the relevant industrial and academic stakeholders can be trained in virtual commissioning.

The remainder of this paper is divided into four sections. Section 2 will present the Aalborg University learning factory which lies the foundation for the VCLP presented in Section 3. Section 3 gives also a brief introduction to virtual commissioning. Section 4 describes our learning activities within the VCLP exemplified by two cases and our reflections. Lastly, we conclude the paper in Section 5.

Fig. 1. Illustration of the AAU Smart Production Lab. [8]

2. Aalborg University Smart Production Lab

Aalborg University (AAU) has commissioning a Smart Production lab in August 2016 [9]. The Smart Production lab is built around the FESTO Cyber-Physical didactic learning factory, stationary and mobile collaborative robots, automated guided vehicle (AGV) and a traditional robot cell, see Fig. 1. The learning factory is classified as a narrow sense learning factory, due the physical manufactured product, the real value chain, and the on-site communication channel [1].

The physical manufactured product is a dummy cellphone. The cellphone has a variety of options; 3 different colored product houses, number and location of holes drilled in the product house, with/without circuit board, with/without product cover also in 3 colors, and lastly the number and location of fuses in the circuit board. In total, 252 variants of the product are possible, in the same learning factory. The real value chain can be changed/reconfigured in the physical system by exchange, add, and/or remove modules using the principles of RMS [10].

The AAU Smart Production Lab has two main categories of modules: Transportation modules and Process modules. The transportation modules are stationary modules which use conveyors to transport carriers around in the manufacturing system. Currently there are 3 different types of transportation modules; a linear transportation module, a T-junction module with the possibility to divert the carries path and a sidetrack module which gives the possibility to overtake carries. The linear module has two place holders for the process modules whereas the others only have one placeholder. The AAU Smart Production Lab consists of 6 linear modules, 1 T-junction module, and 1 sidetrack module. This availability creates the opportunity of having 224 different layouts of the transportation modules.
The value-adding modules are the process modules. These are either mounted on the top of the transportation modules or by the side as, e.g., a robot cell, collaborative robot, and manual stations. The AAU Smart Production lab currently has 11 process modules. The on-site communication is between the PLCs programmed in CODESYS [11], robot controller and the Manufacturing Executing System (MES). Each transportation module has two PLCs, one for each side, controlling the conveyor and the process module on top. In total, the AAU Smart Production Lab has 14 PLCs, note the T-junction and sidetrack module only have one PLC each. When a carrier arrives at a station, a RFID reader reads the carrier ID, product information, product recipe, next operation, and status. The information is then sent to the MES where process information is sent back to the process module, e.g., drill two holes in the left side in the product house. The industrial robot (part of a process module) and the collaborative robot have their own controller and communicate through the PLC. The OPC UA standard is used to exchange data between the PLCs and the MES.

3. The Virtual Commissioning Learning Platform

VC consists of a virtual plant and the real controls enabling a full emulation of the manufacturing system for verification. VC is identified as one of the topics under the broader term sense learning factory [1,12]. The design procedure for VC consists of four major steps as illustrated in Fig. 2. The first step is process planning which provides a process plan stating the sequence of operations. The second step is the physical device modeling, which involves the modelling of the geometry and kinematics of the devices. The logical device modelling, gives the device its behavior model in the third step. By combining the physical and logical devise model we get virtual devices. As a final fourth step is the system control modeling, where the control logic (in our case PLC-code) is created. The virtual plant is an assembly of the virtual devices. The control code can hereby be tested against the virtual plant. [13]

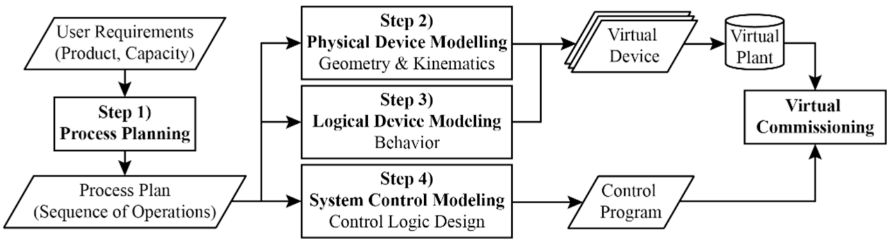

Fig. 2. Design procedure for virtual commissioning. Based on: [10].

3.1. The platform

A VCLP has been constructed based on AAU narrow sense learning factory. The platform is designed to serve two main objectives: for training of step 2-3 of Fig. 2 (i.e. modelling new entities of VC tasks) and for training step 1 and 4 of Fig. 2 (i.e. task planning, system setup and PLC coding/testing). The learning platform consist of three parts the MES, PLC racks and virtual plant, illustrated in Figure 3.

The real MES of AAU Smart Production lab is used to control the PLCs as in the real setup. The real AAU Smart Production lab PLC programs are also used. CODESYS supports a compiler to Raspberry PI 3 making it possible to use Raspberry PI as PLCs and perform hardware-in-the-loop. By having three PLC racks, in total 12 Raspberry PIs, we can expand our PLCs capacity for the tenth of the price compared to commercial PLCs. The virtual plants are built in the commercial software Experior, from the vendor Xcelgo [14]. The virtual plant is built in the model window by

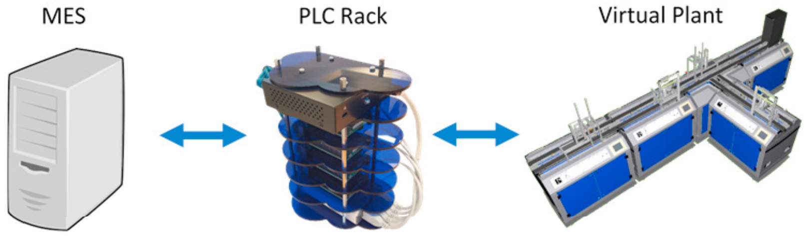

Fig. 3. Setup of the virtual commissioning learning platform

utilizing the modularity of the AAU Smart Production Lab. The AAU Smart Production Lab modules are visually represented in the catalog window, see Figure 4.

Predefined connection points permit snap-fitting of the modules, rendering the task of assembling the virtual plant model easier. The solution explorer gives an overview of the models in model window and a tree structure of the modules. The properties window allows the user to add/change each module's properties like PLC input/output. The PLC input/outputs are linked to the model, in the properties window, by associating the PLC tags (the tags shared by the PLC program by the communication protocol OPC) to the input/output of the modules such as "start conveyor", "piston up" and many more.

4. Learning Activities

Several learning activities have been conducted within the VCLP both Problem Based Learning (PBL) [15] and traditional lectures in courses. The virtual learning platform has been supplementary added in lectures with conventional PLC training in the lab to introduce VC to the students. Firstly, they work with simple PLC tasks in the VCLP before evaluating them in the physical learning factory facilities. In the following, two learning activities that took place within one master student project under the study program Manufacturing Technology are described. The learning activities reflect the two main objectives of the VCLP. The students were working as a group of 4 persons under PBL education.

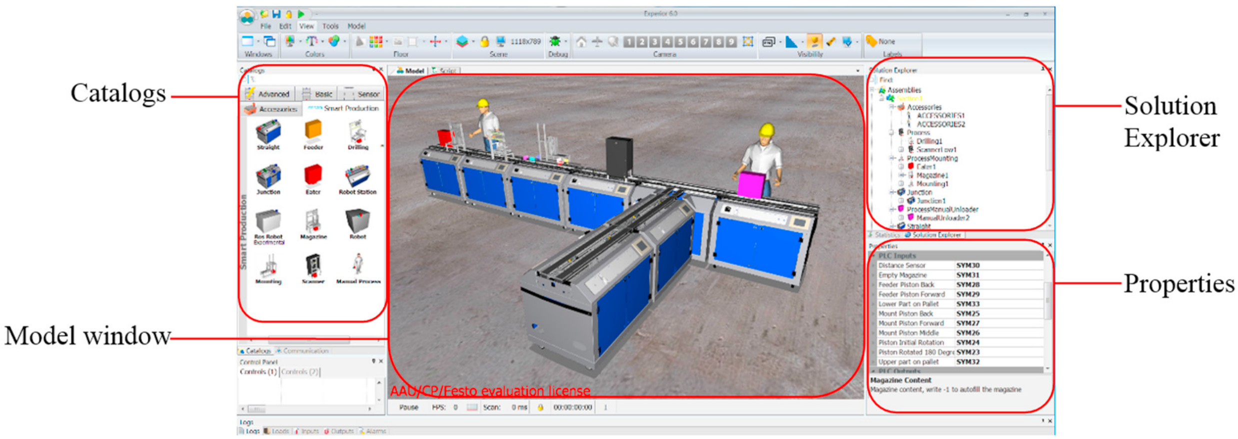

Fig.4. Illustration of the modelling building software.

4.1. Virtual Commissioning of a Single Device

The first challenge was to accomplish a full VC of one of the existing process modules, exploring the flowchart shown in Figure 2, and thereby learning about VC. The first objective was to analyze the desired process module producing firstly a sequence of operations and an I/O list for use in the later design of the logical device modeling. Hereafter, CAD drawings should be converted for virtual representation of the module. Traditionally, in order to lower the need for computational power when running the virtual model, many simulation/emulation tools lower the graphical representation. Converting the CAD drawings is not a trivial task since CAD drawings contain many details that are not necessary for the virtual representation e.g., the inner design of the modules is not needed to model the behavior of the module. The students, therefore, learn how to disassemble, evaluate, simplify and convert the CAD drawing from SLDPRT (SolidWorks format) to COLLADA (open standard format), so a virtual representation of the module could present the needed geometric and kinematic behavior of the module. To set up the kinematic and logic behavior the students had to learn the overall structural of the source code and studied the code of other virtual devices in Experior. Hereby, the students could reuse code samples from other modules to assembly the kinematic and logical behavior code for the new process module. Furthermore, the control program (PLC program) was rewritten and optimized from ladder-diagram to structured text. The virtual process module and control program were hereafter finalized by debugging iterations in the virtual environment. After the VC of the control code was performed, it was implemented and commissioning on the physical process module. The code was executed at the PLC and the process module was able to work within the AAU Smart Production Lab without any software errors.

4.2. Virtual Commissioning of a Reconfigurable Manufacturing System

The second challenge was to explore the reconfiguration abilities of the AAU Smart Production Lab. The challenge was to conduct a virtual *recommissioning* task, increase the throughput of the RMS by duplicated the one of the process modules. Note: "*Virtual recommissioning is defined as the virtual commissioning phase between two configurations in a reconfigurable manufacturing system*" in [16]. The students firstly had to learn the principles and terminology of RMS. Afterwards, understand and learn to operate the AAU Smart Production Lab and obtain the following competencies in the MES; setup of new product, setting sequence of production, reconfiguring the topology settings, order handling and order executing. An understanding of communication between the MES, PLC and RFID tags was also obtained. With the obtained knowledge about the AAU Smart Production Lab the students could manufacture a complete I/O and function list of all transportation and process modules. This lead to the fabrication of the virtual model of all the modules, manufactured by Xcelgo. To reduce the working load, a simple product with only a single-color product house and cover was chosen as the case product. The reconfiguration task was performed from a setup with two transportation modules and 3 process modules (product house dispenser, product cover dispenser and manual unloader) to a new setup with an additional cover dispenser. Note that since the physical learning factory does not have two product cover dispenser modules, the VCLP lets us explore configurations and possibilities that otherwise were not possible to explore. Firstly, a functional virtual model was conducted of the first setup to validate the virtual models working as the physical system with particular focus on the communication with the MES. Afterwards the upscaling of the setup was performed, adding an extra product cover dispenser to the virtual model. The product cover dispenser PLC code was loaded in the respective PLCs. The students revealed that the MES cannot support scaling of the process modules due to the way the MES sets the sequence of operations for the product with specification of resources.

4.3. Reflections Upon Using the Virtual Commissioning Learning Platform

The fact that the students had to perform VC of a single device before the real commissioning provided a deeper understanding of the underlying processes while they developed the appropriate competencies and skills in VC. Our reflection upon the challenges is, by using PBL and a small structured case is that the students were able to clarify the various skills needed for conducting VC. A number of this skills which was acquired was not specified prior to the exercise but was identified by the students on the need basis. The students were forced to learn and familiarize themselves with subjects outside of their own study fields, such as programming and setup of PLCs, C# programs, virtual devices, kinematic and logic modeling, CAD modelling and CAD conversion. Consequently, the students acquired a multidisciplinary set of skills, useful for their future carriers. The second task particularly challenged the students in their overall system thinking. The students obtained understanding about the limitations of the AAU Smart Production lab and were able to formulate suggestions for improvements of the physical learning factory and the VCLP.

In addition to the learning activities we used the VCLP for dissemination activities in industrial events, company training, presentation of the AAU Smart Production Lab and national industrial fairs. The VCLP has proven itself to be excellent in communicating the principles of RMS and VC to non-expert users.

5. Conclusion and Perspective

The construction of a VCLP enabled a well-defined setup to support training of researchers, students, and companies. The VCLP can connect the narrow sense of learning factories with the broader sense of learning factories. The connection lies in the use of real PLCs, with the working code from a narrow sense learning factory, and then is used to emulate the virtual plant. Having a physical learning factory in AAU Smart Production Lab offers the opportunity to perform real commissioning after the VC increased the learning and understanding of the system. The paper has illustrated, with two cases, how the VCLP can support learning of VC skills such as; system control modelling, control programing, physical device modelling (geometric & kinematic), logical device modelling, and virtual plants and devices construction. The VCLP also proved adequate in terms of supporting the teaching of system thinking, process planning and manufacturing strategies.
Future development of the VCLP incorporates the robot process module and collaborative robots in the virtual environments. The VCLP has also clarified the need for a more flexible MES to fully support our reconfigurable learning factory. The VCLP can also support the development and testing of higher level systems like MES and enterprise resource planning systems.

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